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APPLICATION
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FOR: METHOD AND SYSTEM FOR ERROR DIFFUSION WITH A PLURALITY OF ERROR MEASURES

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METHOD AND SYSTEM FOR ERROR DIFFUSION WITH A

PLURALITY OF ERROR MEASURES

BACKGROUND OF THE INVENTION

Field of the Invention

5   The present invention generally relates to halftoning techniques in printers and displays and, more particularly, to a method and apparatus for halftoning with a display or printing medium such that the displayed (or printed) image pixels have different characteristics depending on conditions of the viewing environment such as viewing angle, temperature and lighting

10   conditions.

The inventive halftoning method and apparatus generate a halftoned output such that a different image is displayed under each condition of the viewing environment.

Description of the Related Art

15   Most printers and displays show images which look relatively the same under different viewing conditions. However, this is not true for all printing technologies and displays. For instance, for a type of LCD (Liquid Crystal

Display) display commonly used in laptop computers, the image pixels change color and brightness drastically as the viewing angle is changed. Other examples include inks which change color or density, as the temperature is changed, or inks which change color or density when the printed paper is

5   illuminated with ultraviolet light.

Given images N_1, N_2, ..., a problem arises of how to generate an image such that it looks like N_1 under viewing condition 1, it looks like N_2 under viewing condition 2, etc.

Further, because images printed by a printer or displayed on a display

10   can change color characteristics as the conditions of the viewing environment change, another problem arises as to how to generate images which look the same even as these viewing conditions change.

Other systems exist which display two or more images depending on viewing angles, such as those used on decals, baseball cards, etc. There are

15   several differences between these systems and the present invention. First, these printed papers in the conventional systems are designed to display different images at different angles, and thus no special processing of the image is needed. In the present invention, the display (or printing medium) is not specifically designed to display different images at different viewing

20   conditions, and therefore the present invention teaches methods to process the images so that the display will show different images under different viewing conditions.

Second, the conventional systems mainly deal with different viewing

angles, whereas the present invention can also be applied to showing different

images under different lighting conditions, temperature, etc.

Third, the conventional systems are mainly applicable to printed

5   images, whereas the present invention is also applicable to displays which can

accommodate video.

SUMMARY OF THE INVENTION

In view of the foregoing and other problems of the conventional

methods and systems, an object of the present invention is to provide a system

10   and method which can generate an image such that it looks like N_1 under

viewing condition 1, it looks like N_2 under viewing condition 2, etc.

Another object is to maintain color characteristics of images printed by

a printer or displayed on a display as the conditions of the viewing

environment change, and to generate images which look the same even as

15   these viewing conditions change.

In a first aspect of the present invention, a method (and system) for

producing a halftoned image, includes calculating errors corresponding to a

plurality of different viewing conditions of a halftone image, and minimizing a

function of the errors, such that the halftoned image appears as a different

image under different viewing conditions.

In a different aspect, the halftoned image appears as the same image under different viewing conditions.

Conditions of the viewing environment include variables such as temperature, viewing angle, humidity, lighting conditions, etc. Herein, these will be termed *viewing conditions* for short. A specific viewing condition could be viewing the display (or printed output) at a specific angle (or angle ranges) or the like.

In the following discussion, whenever a display" is referred to, it should be understood that this includes any output device, such as a laptop LCD display, printer, cathode ray tube (CRT), etc.

At each pixel, the display can display one color out of a set of colors $\{c_1, c_2, ..., c_n\}$.

Given a color c_i, the actual color seen by the viewer under viewing condition j will be denoted a_{ij}. a_{ij} can be a scalar for grayscale or a three-dimensional vector for color in RGB, LAB, CMY, XYZ or other color spaces. An introduction to color spaces can be found in "Color Technology for Electronic Imaging Devices", H. R. Kang, SPIE Press, 1997. It is clear how this formulation is also valid for other high dimensional color spaces.

In classical error diffusion halftoning, halftoning errors from previous pixels are added to the input pixel resulting in the modified input. The displayable color closest to the modified input is then displayed. The

difference between the modified input and the printed (displayed) color is the halftoning error which is propagated to neighboring pixels.

Error diffusion and other halftoning techniques are described in the book "Digital Halftoning" by R. Ulichney, MIT Press, 1987.

5   Assume that images N_1, N_2, ... are given. By using a_{ij} instead of c_i and choosing N_j, an error e_j corresponding to the viewing condition j for halftoning image N_j can be obtained. In the present invention, a halftoned image is generated which attempts to minimize the aggregate error which is a function of the e_j's.

10   Thus, with the unique and unobvious aspects of the present invention, an image can be generated such that it looks like N_1 under viewing condition 1, it looks like N_2 under viewing condition 2, etc.

Further, in a different aspect, color characteristics can be maintained of images printed by a printer or displayed on a display as the conditions of the

15   viewing environment change. Thus, images can be generated which look the same even as the viewing conditions change.

Hence, with the invention, several different error measures can be considered and the color selected minimizes the error measures jointly by minimizing an aggregate of the error measures.

20   Typically, error diffusion methods result in selecting one color from a limited set of colors at each pixel. Traditionally, error diffusion tries to minimize the error between what image is output and what the original image

actually is. Typically, an attempt is made to pick the right color such that at a distance the output appears the same as the original.

However, in contrast to the conventional methods, there are a plurality (e.g., two or more) of errors considered in the present invention. For example, there may be one error looking at an image at one viewing condition (e.g., angle, temperature, lighting condition, etc.) and displaying it, and there may be another error in viewing the same image at another viewing condition (e.g., angle, temperature, etc.) and displaying it. Thus, there are two errors, but the conventional methods attempt to minimize only one of them.

In the inventive method, the error diffusion is performed by minimizing an aggregate of the errors (e.g., at the same time), not just one error or the other as in conventional error diffusion. Thus, colors are selected to minimize the errors at each pixel.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, aspects and advantages will be better understood from the following detailed description of a preferred embodiment of the invention with reference to the drawings, in which:

Figure 1A illustrates a flow diagram of a method for performing error diffusion with a plurality of error measures according to a preferred

embodiment of the invention ;

Figure 1B illustrates the preferred embodiment of the invention of Figure 1 in pseudo-code form;

Figure 2A is an image generated from the prescribed algorithm viewed on a LCD display from one angle;

Figure 2B is the same image as Figure 2A viewed from another angle;

Figure 2C is a color image generated from the prescribed algorithm viewed on an LCD display from one angle;

Figure 2D is the same image as Figure 2C viewed from another angle (in contrast to Figures 2A-2B, the same image is embedded in the two viewing angles so that the same image of a young woman appears under both viewing angles.);

Figure 3 shows curves for a_{i1} and a_{i2} which would work well to embed two images;

Figure 4 illustrates an exemplary information handling/computer system for use with the present invention; and

Figure 5 illustrates a storage medium 500 for storing steps of the program for the method according to the present invention.

DETAILED DESCRIPTION OF A PREFERRED

EMBODIMENT OF THE INVENTION

Referring now to the drawings, and more particularly to Figures 1A-5, there are shown preferred embodiments of the method and structures

5   according to the present invention.

Figure 1A illustrates a flow chart of the inventive method 100, and Figure 1B illustrates the inventive method in pseudo-code form.

In Figure 1A-1B, there are three loops in the process such that a loop is made through each column k and rows 1 of the image (e.g., through each

10   pixel).

That is, in step 110, for each pixel of the image (e.g., at the intersection of the columns and rows), a loop is made through each viewing condition. In the example of Figures 2A-2B, there are only two viewing conditions shown for simplicity (e.g., one showing the baboon and one showing the woman).

15   In step 120, for each viewing condition, a modified input M_j is created. In error diffusion, instead of using an input, a modified input is used (created) by adding to the current input pixel N a weighted sum (w_j) of errors (e_j) that have been generated in the past (e.g., errors propagated through).

Once the modified inputs are generated, then, in step 130 for example,

20   the aggregate error is calculated for each possible output color. The aggregate error can be chosen as the sum of the errors for each viewing condition.

In step 140, the color for the halftone image output pixel is chosen as the output color which has a small (or the lowest) aggregate error.

In step 150, the error e_j that can occur by selecting a particular output then is found for each viewing condition j. That is, a particular output is subtracted from the modified output M.

Then, in step 160, for each j, an upper and lower bound is applied to the error such that the error does not grow too large in magnitude. Thus, the error is clamped at an upper bound and a lower bound if it becomes too large. Hence, if the error is larger than the upper bound, it is clamped at the upper bound value. A similar operation is performed at the lower bound if the error is smaller than the lower bound.

Finally, in step 170, an output of the halftone image is generated such that the appearance of the image changes as the viewing conditions change.

Hence, given images N_1, N_2, ..., the system and method of the present invention create a halftoned image which looks like image N_j under viewing condition j for each j. The images N_1, N_2, ..., will be termed as being *embedded* into the halftoned image. $N_j(k,l)$ will be denoted as the (k,l)th pixel of image N_j. Each pixel of N_j is a scalar or a vector, depending on whether the image is a grayscale image or a color image.

Furthermore, the pixels of each image N_j can be represented in different color spaces (i.e., N_1 can be in RGB space, N_2 can be in LAB space, N_3 can be used in CMY space, etc.). For each image, the corresponding colors

a_{ij} and $M_j(k,l)$ are represented in the same color space as the image. Using the notation as above, the modified input for viewing condition j is defined as

$$M_j(k,l) = N_j(k,l) + \sum_{u,v} w_j(u,v)e_j(k-u,l-v)$$

where $e_j(k, l)$ is the error corresponding to viewing condition j at the (k, l)th pixel. The aggregate error in the preferred embodiment at the (k, l)th pixel for choosing c_i as the output pixel color is given by:

$$Err(i,k,l) = \sum_j |M_j(k,l)-a_{ij}|$$

This definition of Err is based on a L_1 norm. It is clear how other definitions of Err can be possible. For example, Err based on a L_2 norm is defined as:

$$Err(i,k,l) = (\sum_j |M_j(k,l)-a_{ij}|^2)^{\frac{1}{2}}$$

and Err based on a weighted L_1 norm is defined as

$$Err(i,k,l) = \sum_j n_j |M_j(k,l)-a_{ij}|$$

where n_j are the weighting terms.

The output pixel color at the (k,l)th pixel is then defined as:

$$o(k,l) = c_t \text{ where } t = \operatorname*{argmin}_i Err(i,k,l)$$

(i.e., $o(k, l)$ is the printable color c_t which minimizes the aggregate error Err).

The error $e_j(k,l)$ is defined as $M_j(k,l) - a_{mj}$ if and only if $o(k,l) = c_m$.

w_j is the error weights matrix corresponding to the error diffusion

5 algorithm. For instance, if Jarvis error diffusion (e.g., see Ulichney mentioned above) is used for each j, then w_j will be defined as shown below in Table 1.

TABLE 1

u

	$w_j(u,v)$	2	1	0	1	2
	0	0	0	0	7/48	5/48
v	1	3/48	5/48	7/48	5/48	3/48
	2	1/48	3/48	5/48	3/48	1/48

Thus, Table 1 shows the weighting factors that can be exemplary used.

10 To prevent the error from growing too large, if $e_j(k,l) >$ UPBOUND$_j$ then

$e_j(k,l)$ is set to UPBOUND$_j$. Similarly, if $e_j(k,l) <$ LOBOUND$_j$ then $e_j(k,l)$ is

set to LOBOUND$_j$. UPBOUND$_j$= 10 and LOBOUND$_j$= 10 are set for all j in a

preferred embodiment.

It is clear to one skilled in the art that the present invention can be

15 adapted to many variations of error diffusion, such as using different error

weights, or using error weights which are input dependent (e.g., see U.S. Patent No. 6,006,011, incorporated herein by reference) etc.

In general, for printers, the number of printable colors is small (i.e., 2 for a black-and-white printer, and 8 for a CMYK bilevel color printer).

5   In general, for displays, the list of displayable colors can be quite large. For 8-bit grayscale, the number of displayable colors can be as much as 256 which is still manageable. For 24-bit RGB color, the number of displayable colors can be too large to implement the present invention efficiently. In that case, the images can be split into their RGB channels (or LAB channels or any

10   appropriate color channels) and apply the present invention to each channel independently. In this case, all images should be expressed in the same color space. Another solution is to restrict the number of displayable colors to a manageable size, which depends on the processing speed of the hardware responsible for implementing the present invention.

15   The present invention is shown in Fig. 1B in pseudo-code form. As mentioned above, the halftoned image is given by o, i.e., $o(k,l)$ is the (k,l)th pixel of the output halftoned image.

One of the applications of the present invention is to display different images depending on the viewing conditions.

20   Another application is to display images of warning messages for certain viewing conditions, such as when the temperature is too high, the viewing angle is too low, etc.

The present invention also can be used to limit the viewing conditions under which the intended image can be viewed by embedding other images for the unintended viewing conditions.

Another application is in counterfeit protection, where

5   temperature-sensitive inks are used and a second image only appears when the printed paper is heated up by placing a finger on it. Such technology is currently used, but the second image is usually very simple and bilevel, such as an image of the word "authentic". The present invention allows more complicated multilevel images to be embedded as a security feature. Similarly

10   the same can be done with inks which are sensitive to ultraviolet light and the second image will appear when the document is illuminated with a ultraviolet light source.

Fig. 2A shows a halftoned image generated from the present invention when viewed from one viewing angle on an LCD display for the case when

15   the image is a grayscale image. That is, Fig. 2A shows an image of a baboon Two viewing conditions are used corresponding to two different viewing angles and 4 grayscale output colors are used as shown in Table 2 below.

TABLE 2

i

	1	2	3	4
c_i	0	40	180	255
a_{i1}	0	40	180	255
a_{i2}	0	115	3	255

Thus, Table 2 shows the 4 output colors c_i and how they appear under viewing condition 1 (a_{i1}) and viewing condition 2 (a_{i2}). The two viewing conditions are the viewing angles as defined by the angle between the viewer's viewing direction and the normal direction (the perpendicular direction) of the image.

Fig. 2B shows the same halftoned image viewed from another viewing angle. As shown, the image is now of a young woman. Another application is to increase the robustness of the image under varying viewing conditions (i.e., the printed (or displayed) image should look the same under different viewing conditions). In this case, the images N_1, N_2, ... are chosen to be the same image.

For example, a halftoned image was generated where the same color image was embedded in the two viewing angles. In this case, the image is

into its RGB channels and the algorithm is applied to each color channel using

Table 2. Fig. 2C and Fig. 2D show this image as viewed under the two

viewing angles respectively. One sees that the same image of a young woman

appears under the two viewing conditions.

5   Since video can be decomposed as a series of still images, the present

invention also can be used to embed several video sequences in a display, each

of which can be seen under different viewing conditions.

If the color does not change much under a different viewing condition,

then it is very unlikely that the image will appear substantially different under

10   different viewing conditions. Therefore, to successfully embed several very

different images, the sequences $\{a_{ij}\}$ as a function of i should be very different

for different j. For instance, in the example above, $\{a_{i1}\}$ is monotonic, while

$\{a_{i2}\}$ is not. In the grayscale case, preferably, the following condition should

hold: for each viewing condition j, assign one of the two labels "light" or

15   "dark". For any such combination of labels for the viewing conditions, there

exists a index i such that a_{ij} for each j corresponds to the chosen label, i.e. a_{ij} is

dark if viewing condition j has label "dark" , a_{ij} is light if viewing condition j

has label "light" , for each viewing condition j. For example, for two viewing

conditions, the two curves shown in Fig. 3 will work well.

20   Figure 3 shows a scheme (conditions) in which the images will appear

different and will allow the image(s) to look different under two different

viewing conditions. In particular, Figure 3 illustrates two curves showing how

the gray levels (color) of the image pixels depend upon the input i for the two viewing conditions.

That is, a relationship is shown between the input value and the perceived color of the image pixels for the two viewing conditions. In an idealized image pixel, a linear relationship would exist in which as the input becomes greater, the color becomes darker. Hence, for example, a_{i1} is the gray level of a normalized pixel under one viewing condition. Thus, as the brightness is increased (e.g., the input), the darkness of the pixel is increased monotonically.

The second curve a_{i2} illustrates the same image pixel under a second, different viewing condition. As shown, a small amount of input (e.g., turning the image pixel on slightly) will result in very dark pixel, and when the input is increased more then the pixel becomes lighter until the very end of the curve. Hence, in the second curve, the input value and the perceived color have almost an inverse relationship. As shown, at some point of the horizontal axis i, there is a case of when the first viewing condition is low and the second condition is high, or vice versa, or some cases when the first and second viewing conditions are both low (e.g., at the beginning of the curves where i is almost 0) and are both high (e.g. at the end of the curve where i is large).

As shown below in Table 3, for the following values of c_i and a_{ij}:

TABLE 3

i

	1	2	3	4
c_i	0	1	254	255
a_{i1}	0	0	255	255
a_{i2}	0	255	0	255

there is a simple interpretation of the resulting invention. That is, two images

are independently halftoned by bilevel error diffusion. At each pixel position,

5   the pixels of the two halftoned images form a pixel pair of one of the

following four forms: (0, 0), (0, 255), (255, 0) and (255, 255), from which the

output color is chosen as 0, 1, 254, 255, respectively.

While the overall methodology of the invention is described above, the

invention can be embodied in any number of different types of systems and

10   executed in any number of different ways, as would be known by one

ordinarily skilled in the art.

For example, as illustrated in Figure 4 , a typical hardware

configuration of an information handling/computer system for use with the

invention. In accordance with the invention, preferably the system has at least

15   one processor or central processing unit (CPU) 411 and more preferably

several CPUs 411. The CPUs 411 are interconnected via a system bus 412 to a random access memory (RAM) 414, read only memory (ROM) 416, input/output (I/O) adapter 418 (for connecting peripheral devices such as disk units 421 and tape drives 440 to the bus 412), user interface adapter 422 (for

5   connecting a keyboard 424, an input device such as a mouse, trackball, joystick, touch screen, etc. 426, speaker 428, microphone 432, and/or other user interface device to the bus 412), communication adapter 434 (for connecting the information handling system to a data processing network such as an intranet, the Internet (World-Wide-Web) etc.), and display adapter 436

10   (for connecting the bus 412 to a display device 438). The display device could be a cathode ray tube (CRT), liquid crystal display (LCD), etc., as well as a hard-copy printer (e.g., such as a digital printer).

In addition to the hardware/software environment described above, a different aspect of the invention includes a computer-implemented method for

15   producing a halftone image. This method may be implemented in the particular environment discussed above.

Such a method may be implemented, for example, by operating a computer, as embodied by a digital data processing apparatus, to execute a sequence of machine-readable instructions. These instructions may reside in

20   various types of signal-bearing media.

Such a method may be implemented, for example, by operating the CPU 411 (Figure 4), to execute a sequence of machine-readable instructions.

These instructions may reside in various types of signal-bearing media.

Thus, this aspect of the present invention is directed to a programmed product, comprising signal-bearing media tangibly embodying a program of machine-readable instructions executable by a digital data processor

5   incorporating the CPU 411 and hardware above, to perform the above method.

This signal-bearing media may include, for example, a RAM (not shown in Figure 4) contained within the CPU 411 or auxiliary thereto as in RAM 414, as represented by a fast-access storage for example. Alternatively, the instructions may be contained in another signal-bearing media, such as a

10   magnetic data storage diskette 500 (e.g., as shown in Figure 5), directly or indirectly accessible by the CPU 411.

Whether contained in the diskette 500, the computer/CPU 411, or elsewhere, the instructions may be stored on a variety of machine-readable data storage media, such as DASD storage (e.g., a conventional "hard drive"

15   or a RAID array), magnetic tape, electronic read-only memory (e.g., ROM, EPROM, or EEPROM), an optical storage device (e.g., CD-ROM, WORM, DVD, digital optical tape, etc.), paper "punch" cards, or other suitable signal-bearing media including transmission media such as digital and analog and communication links and wireless. In an illustrative embodiment of the

20   invention, the machine-readable instructions may comprise software object code, compiled from a language such as "C", etc.

Thus, with the unique and unobvious aspects of the present invention,

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a method (and system) are provided which can generate an image such that it looks like N_1 under viewing condition 1, it looks like N_2 under viewing condition 2, etc.

Further, color characteristics of images printed by a printer or displayed on a display can be maintained as the conditions of the viewing environment change, and which can generate images which look the same even as these viewing conditions change.

Further, in the invention, a halftoned image is generated which attempts to minimize the aggregate error which is a function of the e_i_s.

Thus, with the unique and unobvious aspects of the present invention, an image can be generated such that it looks like N_1 under viewing condition 1, it looks like N_2 under viewing condition 2, etc.

Further, color characteristics can be maintained of images printed by a printer or displayed on a display as the conditions of the viewing environment change. Thus, images can be generated which look the same even as the viewing conditions change (e.g., an image of a baboon under one viewing condition would look the same under another viewing condition).

Hence, with the invention, several different error measures can be considered and, for example, several different colors can be considered such that the color selected has to be constrained. Further, the error diffusion method of the invention tries to minimize the error between what image is output and what the original image actually is. In contrast to the conventional

methods, there are a plurality (e.g., two or more) of errors considered. Moreover, in the inventive method, the error diffusion is performed by minimizing an aggregate of the errors (e.g., at the same time), not just one error or the other as in conventional error diffusion. Thus, colors are selected

5   to minimize the errors at each pixel.

While the invention has been described in terms of a single preferred embodiment, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the appended claims.